

To Recd

09 JAN 2002

#6

File No. 4463

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT: Euler et al. **GROUP:** Unknown
SERIAL NO: 09/762,863 **EXAMINER:** Unknown
PCT/US99/19601
FILED: Int. Filing Date: August 25, 1999
Domestic Filing Date: February 14, 2001
FOR: THIN FILM STRAIN SENSORS BASED ON
INTERFEROMETRIC OPTICAL MEASUREMENTS

Assistant Commissioner of Patents
Washington, D.C. 20231

Sir:

RECEIVED

09 JAN 2002

Legal Staff
International Division

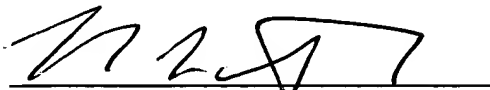
RENEWED PETITION UNDER 37 C.F.R. §1.47(a)

The Decision on Petition Under 37 C.F.R. §1.47(a) dated September 7, 2001 has been received and carefully considered.

Enclosed is a declaration from the undersigned which attests to the fact that Gregg S. Huston of 23 Tomahawk Trail, Wakefield, Rhode Island 02879 and named joint inventor of the above-referenced application ("Application") could not be located after diligent effort. As set forth in the declaration, a certified copy of the Application was forwarded to Mr. Huston on October 1, 2001 and was returned by the United States Postal Service stamped October 9, 2001. See Exhibit B. Further, the undersigned attests that the middle name of Mr. Huston, as well as the number of his residential address, were typed incorrectly on the Application, the correct middle name and the correct number being set forth in enumerated paragraph 2 of the Statement of Facts that was filed by Mr. William B. Euler on May 2, 2001 (C of M).

In view of the foregoing, Applicant respectfully requests that the Petition filed on May 2, 2001 (C of M) be reconsidered.

Respectfully submitted,



Richard L. Stevens, Jr.
Registration No. 44,357
Samuels, Gauthier & Stevens
225 Franklin Street, Suite 3300
Boston, Massachusetts 02110
Telephone: (617) 426-9180
Extension: 123

04/11/2002 UEDUVIJE 00000112 190079 09762863

01 FC:217 460.00 CH

10 Recd. 10/10/01 09 JAN 2002

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT: Euler et al.

GROUP: Unknown

SERIAL NO: 09/762,863

EXAMINER: Unknown

FILED: February 14, 2001

FOR: THIN FILM STRAIN SENSORS BASED ON INTERFEROMETRIC
OPTICAL MEASUREMENTS

Hon. Commissioner of Patents and Trademarks
Washington, D.C. 20231

STATEMENT OF FACTS IN SUPPORT OF FILING ON BEHALF OF NONSIGNING
INVENTOR PURSUANT TO 37 C.F.R. §1.47

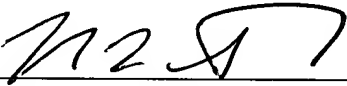
Now comes Richard L. Stevens, Jr. who declares as follows:

- 1) That I am an attorney of record for the above-referenced application;
- 2) That, through typographical error, the name of one of the joint inventors for the above-referenced application was listed as Gregg C. Huston, and the address of Mr. Huston was listed as 29 Tomahawk Trail, Wakefield, Rhode Island 02879;
- 3) That the correct name and last known address of Mr. Huston is Gregg S. Huston of 23 Tomahawk Trail, Wakefield, Rhode Island 02879;
- 4) That on October 1, 2001, a copy of the above-identified application and a Declaration and Power of Attorney was forwarded via certified mail to Mr. Huston at the address set forth in enumerated paragraph 3, a copy of which is enclosed as Exhibit A.

5) That on October 9, 2001, the United States Postal Service returned the documents forwarded to Mr. Huston in enumerated paragraph 4 together with a return receipt, a copy of which is enclosed as Exhibit B;

6) That, to date, the undersigned is unaware of the whereabouts of Mr. Huston.

Richard L. Stevens, Jr., being hereby warned that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent resulting therefrom and that all statements made of his own knowledge are true and all statements made on information and belief are believed to be true.

By: 
Richard L. Stevens, Jr.

Date: 10/16/01

Title: Attorney of Record

SAMUELS, GAUTHIER & STEVENS LLP

ATTORNEYS AT LAW
PATENTS TRADEMARKS AND COPYRIGHTS

225 FRANKLIN STREET, SUITE 3300
BOSTON, MASSACHUSETTS 02110

TELEPHONE (617) 426-9180

Writer's Extension: 122

E-Mail: rstevens@sgslaw.com

RECEIVED FAX (617) 426-2275

OCT 9 2001

October 1, 2001

Samuels, Gauthier & Stevens LLP

Certified Mail

Return Receipt Requested

Gregg S. Huston
23 Tomahawk Trail
Wakefield, Rhode Island 02879

Re: United States National Phase Pat. Appln.
corresponding to PCT/US99/19601
THIN FILM STRAIN SENSORS BASED ON
INTERFEROMETRIC OPTICAL MEASUREMENTS
Your File: URI-141
Our File: 4463


Dear Mr. Huston:

This will confirm that the above-identified application entered the United States on February 14, 2001. Enclosed for your records is a copy of the application as filed.

In order to complete the filing requirements, the enclosed Declaration and Power of Attorney must be filed with the United States Patent and Trademark Office. Accordingly, please execute the Declaration and Power of Attorney where indicated and return the same to my attention.

Your prompt attention to this matter will be appreciated.

Very truly yours,



Richard L. Stevens

RLS:jac

Enclosure

COMBINED DECLARATION AND POWER OF ATTORNEY

*(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL,
CONTINUATION OR CIP)*

As a below named inventor, I hereby declare that:

TYPE OF DECLARATION

This declaration is of the following type: *(check one applicable item below)*

- ☒ original
☐ design
☐ supplemental

NOTE: If the declaration is for an International Application being filed as a divisional, continuation or continuation-in-part application, do not check next item; check appropriate one of last three items.

- ☒ national stage of PCT (under 35 U.S.C. §371)

NOTE: If one of the following 3 items apply, then complete and also attach ADDED PAGES FOR DIVISIONAL, CONTINUATION OR CIP.

- ☐ divisional
☐ continuation
☐ continuation-in-part (CIP)

INVENTORSHIP IDENTIFICATION

WARNING: If the inventors are each not the inventors of all the claims, an explanation of the facts, including the ownership of all the claims at the time the last claimed invention was made, should be submitted.

My residence, post office address and citizenship are as stated below next to my name. I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

THIN FILM STRAIN SENSORS BASED ON INTERFEROMETRIC OPTICAL MEASUREMENTS
SPECIFICATION IDENTIFICATION

the specification of which: *(complete (a), (b) or (c))*

- (a) ☐ is attached hereto.
 (b) ☒ was filed on February 14, 2001 as ☒ Serial No. 09/762,863 or ☒ Express Mail No., as Serial No. not yet known EL733959046US and was amended on _____ *(if applicable)*.
 (c) ☐

NOTE: Amendments filed after the original papers are deposited with the PTO which contain new matter are not accorded a filing date by being referred to in the declaration. Accordingly, the amendments involved are those filed with the application papers or, in the case of a supplemental declaration, are those amendments claiming matter not encompassed in the original statement of invention or claims. See 37 CFR 1.67.

- c) ☒ was described and claimed in PCT International Application No. PCT/US99/19601 filed on 25 August 1999 and as amended under PCT Article 19 on _____ *(if any)*.

ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information

X which is material to patentability as defined in 37, Code of Federal Regulations, § 1.56

(also check the following items, if desired)

— and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable examiner would consider it important in deciding whether to allow the application to issue as a patent, and

— In compliance with this duty there is attached an information disclosure statement in accordance with 37 CFR 1.98.

PRIORITY CLAIM (35 U.S.C. § 119)

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

(complete (d) or (e))

(d) — no such applications have been filed.

(e) X such applications have been filed as follows.

NOTE: Where item (c) is entered above and the International Application which designated the U.S. itself claimed priority check item (e), enter the details below and make the priority claim.

A. PRIOR FOREIGN/PCT APPLICATION(S) FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS APPLICATION AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. § 119

COUNTRY (OR INDICATE IF PCT)	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 37 USC 119		
US	60/097,989	26 August 1998	<u>X</u> YES	NO	—
			— YES	NO	—
			— YES	NO	—
			— YES	NO	—
			— YES	NO	—

**PRIORITY CLAIMED ALL FOREIGN APPLICATION(S), IF ANY FILED MORE THAN 12 MONTHS
(6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION**

PCT/US99/19601 filed 25 August 1999

NOTE: If the application filed more than 12 months from the filing date of this application is a PCT filing forming the basis for this application entering the United States as (1) the national stage, or (2) a continuation, divisional, or continuation-in-part, then also complete ADDED PAGES TO COMBINED DECLARATION AND POWER OF ATTORNEY FOR DIVISIONAL, CONTINUATION OR CIP APPLICATION for benefit of the prior U.S. or PCT application(s) under 35 U.S.C. § 120.

POWER OF ATTORNEY

I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (*List name and registration number*)

Maurice E. Gauthier - 20,798
Richard L. Stevens - 24,445
Matthew E. Connors - 33,298

William E. Hilton - 35,192
Patrick J. O'Shea - 35,305
Arlene J. Powers - 35,985
Richard L. Stevens, Jr - 44,357

(*check the following item, if applicable*)

— Attached as part of this declaration and power of attorney is the authorization of the above-named attorney(s) to accept and follow instructions from my representative(s).

SEND CORRESPONDENCE TO

Richard L. Stevens, Esq.
Samuels, Gauthier & Stevens LLP
225 Franklin Street
Suite 3300
Boston, Massachusetts 02110

DIRECT TELEPHONE CALLS TO:
(*Name and telephone number*)

Richard L. Stevens
(617) 426-9180
Extension 122

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

NOTE: Carefully indicate the family (or last) name as it should appear on the filing receipt and all other documents.

Full name of sole or first inventor

William
(GIVEN NAME)

B.
(MIDDLE INITIAL OR NAME)

Euler
FAMILY (OR LAST NAME)

Inventor's signature _____

Date _____ **Country of Citizenship** US

Residence 35 Flintstone Road
Narragansett, Rhode Island 02882

Post Office Address _____

Full name of second joint inventor, if any

Otto
(GIVEN NAME)

J.
(MIDDLE INITIAL OR NAME)

Gregory
FAMILY (OR LAST NAME)

Inventor's signature _____

Date _____ **Country of Citizenship** US

Residence 87 Westwind Road
Wakefield, Rhode Island 02879

Post Office Address _____

Full name of third joint inventor, if any

Gregg
(GIVEN NAME)

S.
(MIDDLE INITIAL OR NAME)

Huston
FAMILY (OR LAST NAME)

Inventor's signature _____

Date _____ **Country of Citizenship** US

Residence 23 Tomahawk Trail
Wakefield, Rhode Island 02879

Post Office Address _____

*CHECK PROPER BOX(ES) FOR ANY OF THE FOLLOWING ADDED PAGE(S) WHICH
FORM A PART OF THIS DECLARATION*

— Signature for fourth and subsequent joint inventors. *Number of pages added* _____.

* * *

— Signature by administrator(trix), executor(trix) or legal representative for deceased or incapacitated inventor. *Number of pages added* _____.

* * *

— Signature for inventor who refuses to sign or cannot be reached by person authorized under 37 CFR 1.47. *Number of pages added* _____.

* * *

— Added page for signature by one joint inventor on behalf of deceased inventor(s) where legal representative cannot be appointed in time (37 CFR 1.47).

* * *

X Added pages to combined declaration and power of attorney for divisional, continuation, or continuation-in-part (C-I-P) application.

X Number of pages added 2

* * *

— Authorization of attorney(s) to accept and follow instructions from representative.

* * *

*(If no further pages form a part of this Declaration, then end this Declaration with
this page and check the following item.)*

— This declaration ends with this page.

Attorney's Docket No. 4463

**ADDED PAGE TO COMBINED DECLARATION AND POWER OF
ATTORNEY FOR DIVISIONAL, CONTINUATION OR C-I-P APPLICATION**

(complete this part only if this is a divisional, continuation or C-I-P application)

**CLAIM FOR BENEFIT OF EARLIER U.S./PCT APPLICATION(S) UNDER
35 U.S.C. 120**

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information that is material to the examination of this application, namely, information where there is substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent, which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application.

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 USC 120:					
U.S. APPLICATIONS			Status (Check One)		
U.S. APPLICATIONS	U.S. FILING DATE		Patented	Pending	Abandoned
1. 0_/_/,_					
2. 0_/_/,_					
3. 0_/_/,_					
PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLI- CATION NO.	PCT FILING DATE	U.S. SERIAL NOS. ASSIGNED (if any)			
4. PCT/US99/19601	25 August 1999 (25.08.99)				
5.					
6.					

**35 USC 119 PRIORITY CLAIM, IF ANY, FOR ABOVE LISTED U.S./PCT
APPLICATIONS**

ABOVE APPLICATION NO.	DETAILS OF FOREIGN APPLICATION FROM WHICH PRIORITY CLAIMED UNDER 35 USC 119		
	Country and Application No.	Date of filing (day, month, year)	Date of issue (day, month, year)
1.			
2.			
3.			
4. PCT/US99/19601	US 60/097,989	26 August 1998	
5.			
6.			

Preliminary Classification:

Proposed Class:

Subclass:

NOTE: "All applicants are requested to include a preliminary classification on newly filed patent applications. The preliminary classification, preferably class and subclass designations, should be identified in the upper right-hand corner of the letter of transmittal accompanying the application papers, for example 'Proposed Class 2, subclass 129.'" M.P.E.P., § 601, 7th ed.

TRANSMITTAL LETTER
TO THE UNITED STATES ELECTED OFFICE (EO/US)

(ENTRY INTO U.S. NATIONAL PHASE UNDER CHAPTER II)

PCT/US99/19601	25 August 1999 (25.08.99)	26 August 1998 (26.08.98)
INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
THIN FILM STRAIN SENSORS BASED ON INTERFEROMETRIC OPTICAL MEASUREMENTS		
TITLE OF INVENTION		
EULER, William B.; GREGORY, Otto J.; HUSTON, Gregg C.		
APPLICANT(S)		

Box PCT
Assistant Commissioner for Patents
Washington D.C. 20231
ATTENTION: EO/US

CERTIFICATION UNDER 37 C.F.R. § 1.10*

(Express Mail label number is mandatory.)

(Express Mail certification is optional.)

I hereby certify that this Transmittal Letter and the papers indicated as being transmitted therewith is being deposited with the United States Postal Service on this date 14 February 2001, in an envelope as "Express Mail Post Office to Addressee" Mailing Label Number EL733959046US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

Julie A. Catalano

(type or print name of person mailing paper)

Julie A. Catalano

Signature of person mailing paper

WARNING: Certificate of mailing (first class) or facsimile transmission procedures of 37 C.F.R. § 1.8 cannot be used to obtain a date of mailing or transmission for this correspondence.

***WARNING:** Each paper or fee filed by "Express Mail" must have the number of the "Express Mail" mailing label placed thereon prior to mailing. 37 C.F.R. § 1.10(b).

"Since the filing of correspondence under § 1.10 without the Express Mail mailing label thereon is an oversight that can be avoided by the exercise of reasonable care, requests for waiver of this requirement will not be granted on petition." Notice of Oct. 24, 1996, 60 Fed. Reg. 56,439, at 56,442.

(Transmittal Letter to the United States Elected Office (EO/US) [13-18]—page 1 of 8)

NOTE: To avoid abandonment of the application, the applicant shall furnish to the USPTO, not later than 20 months from the priority date: (1) a copy of the international application, unless it has been previously communicated by the International Bureau or unless it was originally filed in the USPTO; and (2) the basic national fee (37 C.F.R. § 1.492(a)). The 30-month time limit may be extended. 37 C.F.R. § 1.495.

WARNING: Where the items are those which can be submitted to complete the entry of the international application into the national phase are subsequent to 30 months from the priority date the application is still considered to be in the international state and if mailing procedures are utilized to obtain a date the express mail procedure of 37 C.F.R. § 1.10 must be used (since international application papers are not covered by an ordinary certificate of mailing—See 37 C.F.R. § 1.8).

NOTE: Documents and fees must be clearly identified as a submission to enter the national state under 35 U.S.C. § 371 otherwise the submission will be considered as being made under 35 U.S.C. § 111. 37 C.F.R. § 1.494(f).

- I. Applicant herewith submits to the United States Elected Office (EO/US) the following items under 35 U.S.C. § 371:
- a. ☒ This express request to immediately begin national examination procedures (35 U.S.C. § 371(f)).
 - b. ☒ The U.S. National Fee (35 U.S.C. § 371(c)(1)) and other fees (37 C.F.R. § 1.492) as indicated below:

2. Fees

CLAIMS FEE	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
<input type="checkbox"/> *	TOTAL CLAIMS				
	16	- 20 =	0	× \$18.00 =	\$ 0.00
	INDEPENDENT CLAIMS				
	1	- 3 =	0	× \$80.00 =	0.00
	MULTIPLE DEPENDENT CLAIM(S) (if applicable) + \$270.00				270.00
BASIC FEE**	<input checked="" type="checkbox"/> U.S. PTO WAS INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where an International preliminary examination fee as set forth in § 1.482 has been paid on the international application to the U.S. PTO: <input checked="" type="checkbox"/> and the international preliminary examination report states that the criteria of novelty, inventive step (non-obviousness) and industrial activity, as defined in PCT Article 33(1) to (4) have been satisfied for all the claims presented in the application entering the national stage (37 C.F.R. § 1.492(a)(4)) \$100.00 <input type="checkbox"/> and the above requirements are not met (37 C.F.R. § 1.492(a)(1)) \$690.00 <input type="checkbox"/> U.S. PTO WAS NOT INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where no international preliminary examination fee as set forth in § 1.482 has been paid to the U.S. PTO, and payment of an international search fee as set forth in § 1.445(a)(2) to the U.S. PTO: <input type="checkbox"/> has been paid (37 C.F.R. § 1.492(a)(2)) \$710.00 <input type="checkbox"/> has not been paid (37 C.F.R. § 1.492(a)(3)) \$1000.00 <input type="checkbox"/> where a search report on the international application has been prepared by the European Patent Office or the Japanese Patent Office (37 C.F.R. § 1.492(a)(5)) \$860.00				100.00
	Total of above Calculations				= 370.00
SMALL ENTITY	Reduction by 1/2 for filing by small entity, if applicable. Affidavit must be filed also. Note 37 C.F.R. § 1.491.27.1.28. XXXXXX Small Ent.				-185.00
	Subtotal				185.00
	Total National Fee				\$ 185.00
	Fee for recording the enclosed assignment document \$40.00 (37 C.F.R. § 1.21(h)). (See Item 13 below). See attached "ASSIGNMENT COVER SHEET".				
TOTAL	Total Fees enclosed				\$ 185.00

*See attached Preliminary Amendment Reducing the Number of Claims.

- ☒ Attached is a ☒ check ☐ money order in the amount of \$ 185.00
- ☐ Authorization hereby made to charge the amount
- ☒ to Deposit Account No. 19-0079
- ☐ to Credit card as shown on the attached credit card information authorization form PTO-2038.

WARNING: Credit card information should not be included on this form as it may become public.

- ☒ Charge any additional fees required by this paper or credit any overpayment in the manner authorized above.

A duplicate of this paper is attached.

****WARNING:** "To avoid abandonment of the application the applicant shall furnish to the United States Patent and Trademark Office not later than the expiration of 30 months from the priority date: * * * (2) the basic national fee (see § 1.492(a)). The 30-month time limit may not be extended." 37 C.F.R. § 1.495(b).

WARNING: If the translation of the international application and/or the oath or declaration have not been submitted by the applicant within thirty (30) months from the priority date, such requirements may be met within a time period set by the Office. 37 C.F.R. § 1.495(b)(2). The payment of the surcharge set forth in § 1.492(e) is required as a condition for accepting the oath or declaration later than thirty (30) months after the priority date. The payment of the processing fee set forth in § 1.492(f) is required for acceptance of an English translation later than thirty (30) months after the priority date. Failure to comply with these requirements will result in abandonment of the application. The provisions of § 1.136 apply to the period which is set. Notice of Jan. 3, 1993, 1147 O.G. 29 to 40.

3. ☒ A copy of the International application as filed (35 U.S.C. § 371(c)(2)):

NOTE: Section 1.495 (b) was amended to require that the basic national fee and a copy of the international application must be filed with the Office by 30 months from the priority date to avoid abandonment. "The International Bureau normally provides the copy of the international application to the Office in accordance with PCT Article 20. At the same time, the International Bureau notifies applicant of the communication to the Office. In accordance with PCT Rule 47.1, that notice shall be accepted by all designated offices as conclusive evidence that the communication has duly taken place. Thus, if the applicant desires to enter the national stage, the applicant normally need only check to be sure the notice from the International Bureau has been received and then pay the basic national fee by 30 months from the priority date." Notice of Jan. 7, 1993, 1147 O.G. 29 to 40, at 35-36. See item 14c below.

- a. ☐ is transmitted herewith.
- b. ☒ is not required, as the application was filed with the United States Receiving Office.
- c. ☐ has been transmitted
- i. ☐ by the International Bureau.
Date of mailing of the application (from form PCT/1B/308):

- ii. ☐ by applicant on _____ (Date)

4. ☒ A translation of the International application into the English language (35 U.S.C. § 371(c)(2)):

- a. ☐ is transmitted herewith.
- b. ☒ is not required as the application was filed in English.
- c. ☐ was previously transmitted by applicant on _____ (Date)
- d. ☐ will follow.

5. ☒ Amendments to the claims of the International application under PCT Article 19 (35 U.S.C. § 371(c)(3)):

NOTE: The Notice of January 7, 1993 points out that 37 C.F.R. § 1.495(a) was amended to clarify the existing and continuing practice that PCT Article 19 amendments must be submitted by 30 months from the priority date and this deadline may not be extended. The Notice further advises that: "The failure to do so will not result in loss of the subject matter of the PCT Article 19 amendments. Applicant may submit that subject matter in a preliminary amendment filed under section 1.121. In many cases, filing an amendment under section 1.121 is preferable since grammatical or idiomatic errors may be corrected." 1147 O.G. 29-40, at 36.

- a. ☐ are transmitted herewith.
 - b. ☐ have been transmitted
 - i. ☐ by the International Bureau.
Date of mailing of the amendment (from form PCT/1B/308):

 - ii. ☐ by applicant on _____ (Date)
 - c. ☒ have not been transmitted as
 - i. ☒ applicant chose not to make amendments under PCT Article 19.
Date of mailing of Search Report (from form PCT/ISA/210):
18 Oct 1999
 - ii. ☐ the time limit for the submission of amendments has not yet expired.
The amendments or a statement that amendments have not been made will be transmitted before the expiration of the time limit under PCT Rule 46.1.
6. ☒ A translation of the amendments to the claims under PCT Article 19 (38 U.S.C. § 371(c)(3)):
- a. ☐ is transmitted herewith.
 - b. ☐ is not required as the amendments were made in the English language.
 - c. ☒ has not been transmitted for reasons indicated at point 5(c) above.
7. ☒ A copy of the international examination report (PCT/IPEA/409)
- ☐ is transmitted herewith.
 - ☒ is not required as the application was filed with the United States Receiving Office.
8. ☒ Annex(es) to the international preliminary examination report
- a. ☐ is/are transmitted herewith.
 - b. ☒ is/are not required as the application was filed with the United States Receiving Office.
9. ☒ A translation of the annexes to the international preliminary examination report
- a. ☐ is transmitted herewith.
 - b. ☒ is not required as the annexes are in the English language.

10. ☒ An oath or declaration of the inventor (35 U.S.C. § 1(c)(4)) complying with 35 U.S.C. § 115

- a. ☐ was previously submitted by applicant on _____ Date
- b. ☐ is submitted herewith, and such oath or declaration
- i. ☐ is attached to the application.
- ii. ☐ identifies the application and any amendments under PCT Article 19 that were transmitted as stated in points 3(b) or 3(c) and 5(b); and states that they were reviewed by the inventor as required by 37 C.F.R. § 1.70.
- c. ☒ will follow.

II. Other document(s) or information included:

11. ☒ An International Search Report (PCT/ISA/210) or Declaration under PCT Article 17(2)(a):

- a. ☐ is transmitted herewith.
- b. ☐ has been transmitted by the International Bureau.
Date of mailing (from form PCT/IB/308): _____
- c. ☒ is not required, as the application was searched by the United States International Searching Authority.
- d. ☐ will be transmitted promptly upon request.
- e. ☐ has been submitted by applicant on _____
Date

12. ☒ An Information Disclosure Statement under 37 C.F.R. §§ 1.97 and 1.98:

- a. ☒ is transmitted herewith.
Also transmitted herewith is/are:
- ☒ Form PTO-1449 (PTO/SB/08A and 08B).
- ☒ Copies of citations listed.
- b. ☐ will be transmitted within THREE MONTHS of the date of submission of requirements under 35 U.S.C. § 371(c).
- c. ☐ was previously submitted by applicant on _____
Date

13. ☐ An assignment document is transmitted herewith for recording.

A separate ☐ "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" or ☐ FORM PTO 1595 is also attached.

14. ☒ Additional documents:
- a. ☐ Copy of request (PCT/RO/101)
 - b. ☒ International Publication No. WO 00/12960
 - i. ☒ Specification, claims and drawing
 - ii. ☐ Front page only
 - c. ☐ Preliminary amendment (37 C.F.R. § 1.121)
 - d. ☐ Other
- _____
- _____
- _____

15. ☒ The above checked items are being transmitted
- a. ☒ before 30 months from any claimed priority date.
 - b. ☐ after 30 months.
16. ☐ Certain requirements under 35 U.S.C. § 371 were previously submitted by the applicant on _____, namely:
- _____
- _____
- _____
- _____

AUTHORIZATION TO CHARGE ADDITIONAL FEES

WARNING: Accurately count claims, especially multiple dependant claims, to avoid unexpected high charges if extra claims are authorized.

NOTE: "A written request may be submitted in an application that is an authorization to treat any concurrent or future reply, requiring a petition for an extension of time under this paragraph for its timely submission, as incorporating a petition for extension of time for the appropriate length of time. An authorization to charge all required fees, fees under § 1.17, or all required extension of time fees will be treated as a constructive petition for an extension of time in any concurrent or future reply requiring a petition for an extension of time under this paragraph for its timely submission. Submission of the fee set forth in § 1.17(a) will also be treated as a constructive petition for an extension of time in any concurrent reply requiring a petition for an extension of time under this paragraph for its timely submission." 37 C.F.R. § 1.136(a)(3).

NOTE: "Amounts of twenty-five dollars or less will not be returned unless specifically requested within a reasonable time, nor will the payer be notified of such amounts; amounts over twenty-five dollars may be returned by check or, if requested, by credit to a deposit account." 37 C.F.R. § 1.26(a).

☒ Please charge, in the manner authorized above, the following additional fees that may be required by this paper and during the entire pendency of this application:

☒ 37 C.F.R. § 1.492(a)(1), (2), (3), and (4) (filing fees)

WARNING: Because failure to pay the national fee within 30 months without extension (37 C.F.R. § 1.495(b)(2)) results in abandonment of the application, it would be best to always check the above box.

(Transmittal Letter to the United States Elected Office (EO/US) [13-18]—page 7 of 8)

☒ 37 C.F.R. § 1.492(b), (c) and (d) (presentation of extra claims)

NOTE: Because additional fees for excess or multiple dependent claims not paid on filing or on later presentation must only be paid if these claims cancelled by amendment prior to expiration of the time period set for response to PTO in any notice of fee deficiency (37 C.F.R. § 1.492(d)), it might be best not to authorize the PTO to charge additional claim fees, except possible when dealing with amendments after final action.

☒ 37 C.F.R. § 1.17 (application processing fees)

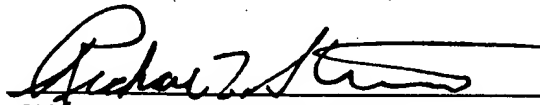
☒ 37 C.F.R. § 1.17(a)(1)-(5) (extension fees pursuant to § 1.136(a).

☐ 37 C.F.R. § 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 C.F.R. § 1.311(b))

NOTE: Where an authorization to charge the issue fee to a deposit account has been filed before the mailing of a Notice of Allowance, the issue fee will be automatically charged to the deposit account at the time of mailing the notice of allowance. 37 C.F.R. § 1.311(b).

NOTE: 37 C.F.R. § 1.28(b) requires "Notification of any change in loss of entitlement to small entity status must be filed in the application . . . prior to paying, or at the time of paying . . . issue fee." From the wording of 37 C.F.R. § 1.28(b): (a) notification of change of status must be made even if the fee is paid as "other than a small entity" and (b) no notification is required if the change is to another small entity.

☐ 37 C.F.R. § 1.492(e) and (f) (surcharge fees for filing the declaration and/or filing an English translation of an International Application later than 30 months after the priority date).



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Boston, MA 02110

Title

Thin Film Strain Sensors Based on Interferometric Optical Measurements

Background of the Invention1. Field of the Invention

5 The invention relates to polymeric/semiconductor thin film strain gauges

2. Description of the Relevant Art

Many civil engineering structures display fatigue, and occasionally failure, after years of exposure to natural forces. In other instances, the failure is a result of a catastrophic event, such as an earthquake, tornado, or hurricane. There is a need for
10 an inexpensive, robust, and sensitive strain gage that is unaffected by seasonal environmental variations. Further, such a sensor should be simple, easily installed, and readily integrated into modern data communication systems.

The sensor system disclosed herein can monitor the integrity of structures for the purpose of public safety and maintenance. Specific applications include building,
15 road, and bridge integrity. The system employs, as the sensing component, multiple optical strain gages that are inexpensive, inert to natural environments, and physically robust. Combined with an automated data collection and diagnostic analysis programming, such sensors and their optical fiber data links can be placed on the superstructures and footings of bridges, in the support components of buildings, or
20 embedded into the surfaces of roads and pedestrian skywalks. The 'health' of such structures and surfaces can be automatically monitored and assessed with a minimum of human time allocation. Detailed use information would also be valuable in assessing the need for routine maintenance or for the need for repair after a potential catastrophic loading.

25 Summary of the Invention

The sensitivity and the passivity behavior of the sensors distinguishes from the prior art. Current resistive strain sensors have gage factors (the measure of sensitivity) of about 2-3. The disclosed sensors have gage factors on the order of 200-800. It is not believed the prior art discloses any passive sensors that have a memory that does

not rely on a power source.

Thin films of semiconductors or polymers are used to measure strain. The thin films are layered with each layer consisting of materials with different refractive indices. Because each layer has a different refractive index, light that is introduced into the composite structure can either be reflected or pass through at each interface. This allows interference of the incident light that passes through with light that is reflected resulting in a measurable absorption change. The degree of interference is sensitive to the refractive index and thickness of each layer. The thickness of the each layer changes with application of an external stress. The consequence of this is that the light absorption changes as a function of strain so that the absorption change can be used to measure the strain.

There are two types of interferometric sensors disclosed herein, active and passive. An active sensor responds to the strain reversibly, i.e. as the strain changes the absorption changes in a reversible and predictable fashion. This type of sensor is used to measure the existing strain on a structure.

A passive sensor has a memory of the maximum strain experienced by the structure. For example, if a structure experiences a large deformation (a large strain) but then relaxes to a small rest value, the large deformation is not reversible. An active sensor will measure the strain events only if continuously monitored while the passive sensor will measure only the maximum strain experienced. If the active sensor is not being monitored while the maximum strain is occurring, the large strain excursion will not be observed. The passive sensor overcomes this problem.

Broadly the invention comprises both active and passive sensors which preferably are used in the same structure. Both sensors are constructed by layering materials, either semiconductors or polymers having different refractive indices. The sensitivity is increased when the difference in refractive index is maximized and also as the number of layers is increased. The passive sensors are constructed by adding small particulates to one set of layers.

Brief Description of the Drawings

Fig. 1 is an illustration of a passive sensor;

Figs. 2a and 2b are illustrations of an alternative embodiment of Fig. 1;

Fig. 3 is a graph of the optical response of an active sensor;
Fig. 4 is a graph of the optical response of an passive sensor; and
Fig. 5 is a graph of the optical response of a passive sensor;

Description of the Preferred Embodiment(s)

5 Incident light can be measured in reflectance or transmission to determine the strain.

Referring to Fig. 1, reflectance mode, visible light from a spectrometer 10, such as Perkin Elmer Lambda 2, is directed onto a thin film passive sensor shown generally at 12. The sensor 12 comprises a transparent glass substrate 14 and a
10 laminated construction in succession from the substrate 14, of a polyimide layer 18a, a polysiloxane layer 16a filled with alumina particles, a polyimide layer 18b and a polysiloxane layer 16b filled with alumina particles. The incident light beam is normal to the sensor surface. The light is collected along the incidence beam path in a photomultiplier tube detector 20 in the spectrometer 10. The layers can range in
15 thickness from 1-20 microns. The passive sensor is prepared by mixing 50 nm particles of aluminum oxide in with the polysiloxane layer in an amount of 0.5 to 10% by weight based on the total weight of the polysiloxane layer. During preparation, the small particles aggregate to some (currently unknown) degree. Under strain, some of the particles in the aggregate separate and the polymer fills in between the newly
20 separated alumina particles. When the strain is removed, the particles cannot reaggregate because of the intervening polymer. This is detected optically because the size of the aggregates determines the amount of light scattered off of the sample: as the aggregate size changes because of the strain, the amount of light directed toward the detector changes since the detector only samples a small volume of space. The passive
25 sensor requires no power to achieve its memory effect.

Referring to Fig. 2a, the transmission mode, for an active sensor a capillary tube 30, e.g. i.d. 0.5 mm; o.d 0.7 mm, is used as a light conduit. Thin films 32, e.g. polysiloxane/polyimide, are deposited onto the outside walls of the capillary tube 30 and then these films are coated with aluminum 34. The aluminum 34 serves as a
30 mirror to keep all the light confined in the tube 30 and to protect the entire structure from the surrounding environment. A fiber optic source 36 inputs light in a

wavelength range of 500 to 1,000 Angstroms into one end of the capillary tube 30 parallel to the longitudinal axis of the tube and a detector 38 collects the light at the other end.

In the capillary configuration, the tube 30 acts as both a waveguide and a
5 sensor. Under no strain, most of the light passes down the tube without interacting with the walls. With application of a strain the capillary tube 30 bends, Fig. 2b, so that a significant amount of light is introduced into the thin film coatings along the tube walls. Two effects cause a modulation of the output light intensity. First, the path length is changed so any absorption that occurs is increased, depending upon the
10 absorptivity of the wall materials and the number of bounces the light undergoes. Second, the interference effect observed as light passes through the thin film layers still is operative, also causing intensity modulation by constructive or destructive interference, depending on the refractive index and thickness of each layer and the wavelength of light used.

15 The film thicknesses 32 are on the order of 1 to 20 microns, thinner being a bit better. The wavelengths of maximum response depends upon the layer thicknesses, but that wavelength can be chosen arbitrarily to match the thin film structure. The aluminum coating has a thickness of between 400 to 800 nm.

The alternating layers must have a different refractive index and the larger the
20 difference, the better the sensor response. Polyimide has $n = 1.6-1.7$ (depending upon the exact polyimide used, the nature of the curing, and the supplier); polysiloxane has $n=1.44$. Other commonly available transparent polymers polyethylene, polypropylene, Teflon®, polyvinylidene fluoride, polyester, etc. have refractive indices around 1.4 and could substitute for the polysiloxane layer. High refractive index
25 polymers such as polycarbonates have refractive indices approximately the same as polyimide.

A preferred sensor system requires both a passive and an active sensor in close proximity. The passive sensor measures the maximum strain excursion experienced but not a temporal history, i.e. the measured strain may be current or previous. Thus,
30 the role of the active sensor is to measure the existing strain at the time of measurement.

The sensors can be applied to a structure by currently known bonding techniques used for the current generation of strain sensors. Because the sensors are small, they will measure the strain of the substrate material reliably. The optical source and detector need not be embedded with the sensor. With the appropriate fiber optic connections, the optical measurement can be made periodically by connecting a handheld spectrometer to the input and output of the sensor. Thus, for example, after an earthquake the maximum strain experienced by each structural element in a building could be determined well after the event (days or weeks) to establish the safety of the building since the passive sensor retains this information even with (the likely) loss of power. Alternatively, a fiber optic network connected to each sensor in a building that remotely senses the strain automatically. However, during a catastrophic event the fiber network is likely to break and prevent this mode of operation.

The materials used in the sensor are both inexpensive and robust. For example, the polysiloxane is a commercially available gasket sealer. The capillary configuration is especially attractive for long term applications because, if necessary, the entire sensor can be enclosed. Then, for example, if the sensor is to be used in a harsh environment such as a bridge, the entire sensor can be isolated from wind, rain, salt spray, etc. because any coatings applied outside of the aluminum layer have no affect on the sensor performance.

20

Examples

Examples of the sensor response are given in Figures 3, 4 and 5. The light source was a tungsten lamp, and strain was applied by four point bending, see ASTM C-1341-97.

Figure 3 shows the response of two different active strain sensors, one with 12 layers (6 alternating layers of polysiloxane and polyimide) and one with 26 alternating layers. Layer thickness was about 10 microns. The absorbance was monitored at 600 nm as a function of applied strain with the results shown. The gage factor is a function of the number of layers indicating the interferometric nature of the response. Further, the gage factors are large, more than two orders of magnitude larger than found in typical resistance strain gages. Finally, the response is linear and reversible over the entire range up to about 2000 μ strain (this is the typical limit required for structural

applications since most materials exceed their plastic deformation limits at about 2000 μ strain).

Figure 4 shows the response of a passive strain gage having 26 alternating layers. The layer thickness was about 10 microns. As strain is applied, the response is similar to an active gage. The absorbance was monitored at 600 nm. However, when the strain is released the response is no longer reversible, i.e., the 0-strain absorbance depends upon the history of the sample. This is demonstrated in Figure 4 for several different strain excursions. The virgin gage has an absorbance value at 600 nm of $A = 0.73$. Application of 300 μ strain changes this to $A = 0.83$. Upon release of the stress back to 0 μ strain the absorbance returns to $A = 0.78$, shown as the short dashed line in Figure 4. Application of any strain less than 300 μ strain follows the dashed line path reversibly. However, if the strain exceeds 300 μ strain, then the path reverts to the solid line as shown for the 600 μ strain point in Figure 4. Now when the stress is released, a new path is taken, shown as the dotted line, and to a new absorbance at 0 μ strain.

The increments between successive strain excursions decreases with increasing strain (i.e., the passive response is nonlinear) and this is demonstrated in Figure 5. The 12 layer gage has a small gage factor but a larger, nearly linear response range. The 26 layer gage has a larger gage factor but becomes clearly nonlinear at significantly smaller maximum strains.

The foregoing description has been limited to a specific embodiment of the invention. It will be apparent, however, that variations and modifications can be made to the invention, with the attainment of some or all of the advantages of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

Having described our invention what we now claim is:

- 1 1. An interferometric strain gage sensor which comprises:
2 a support;
3 a first layer of polymeric material having a first refractive index;
4 a second layer of polymeric material having a second refractive index which
5 second refractive index is distinct from the first refractive index, the sensor having a
6 gage factor of at least 100 and light energy communicates with the sensor, when a
7 strain is applied to the sensor, the light energy is partly absorbed and the change in
8 light energy correlates to the strain applied.
- 1 2. The sensor of claim 1 which comprises:
2 a plurality of alternating first and second layers.
- 1 3. The sensor of claim 2 wherein the first layer has a refractive index of
2 approximately 1.6 to 1.7 and is selected from the group consisting of polyimides and
3 polycarbonates.
- 1 4. The sensor of claim 3 wherein the first layer is polyimide.
- 1 5. The sensor of claim 2 wherein the second layer has a refractive index of
2 about 1.4 and is selected from the group consisting of polysiloxane, polyethylene,
3 polypropylene, Teflon®, polyvinylidene fluoride and polyester.
- 1 6. The sensor of claim 5 wherein the second layer is polysiloxane.
- 1 7. The sensor of claims 4 or 6 wherein the thicknesses of the layers are
2 between about 1 to 20 microns.
- 1 8. The sensor of claim 1 which comprises:
2 means for contacting the sensor with light energy; and
3 means for measuring changes in the light energy.
- 1 9. The sensor of claim 1 wherein the sensor is a passive sensor and one of
2 said layers is filled with particulate.

1 10. The sensor of claim 9 wherein there are multiple first and second layers in
2 alternating relationship, the first layer selected from the group consisting of polyimides
3 and polycarbonates, the second layer selected from the group consisting of
4 polysiloxane, polyethylene, polypropylene, Teflon®, polyvinylidene fluoride and
5 polyester.

1 11. The sensor of claim 10 wherein the first layer is polyimide and the
2 second layer is polysiloxane filled with aluminum oxide particulate.

1 12. The sensor of claim 9 which comprises:
2 means for contacting the sensor with light energy; and
3 means for measuring changes in the light energy.

1 13. The sensor of claim 1 wherein the sensor is an active strain gage and
2 comprises a tube-like support for the first and second layers.

1 14. The sensor of claim 13 wherein the first layer has a refractive index of
2 approximately 1.6 to 1.7 and is selected from the group consisting of polyimides and
3 polycarbonates, and wherein the second layer has a refractive index of about 1.4 and is
4 selected from the group consisting of polysiloxane, polyethylene, polypropylene,
5 Teflon®, polyvinylidene fluoride and polyester.

1 15. The sensor of claim 14 wherein the outer most layer is coated with
2 aluminum.

1 16. The sensor of claim 15 which comprises:
2 means for contacting the sensor with light energy; and
3 means for measuring changes in the light energy.

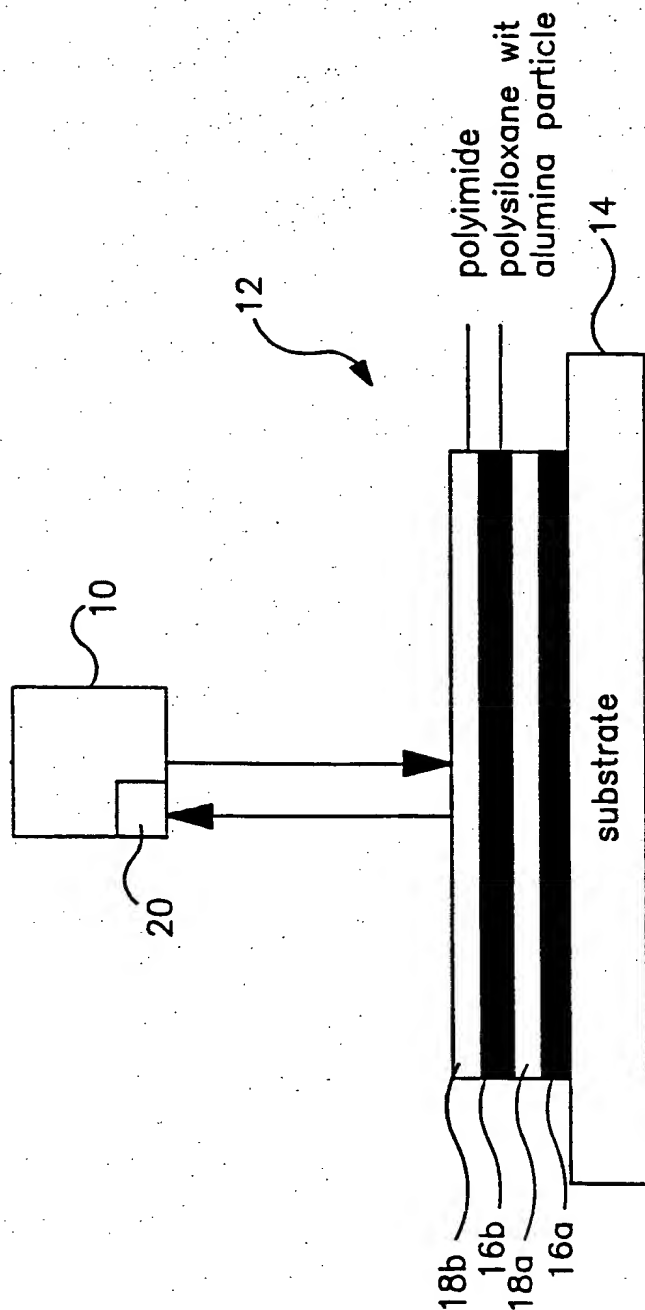


FIG. 1

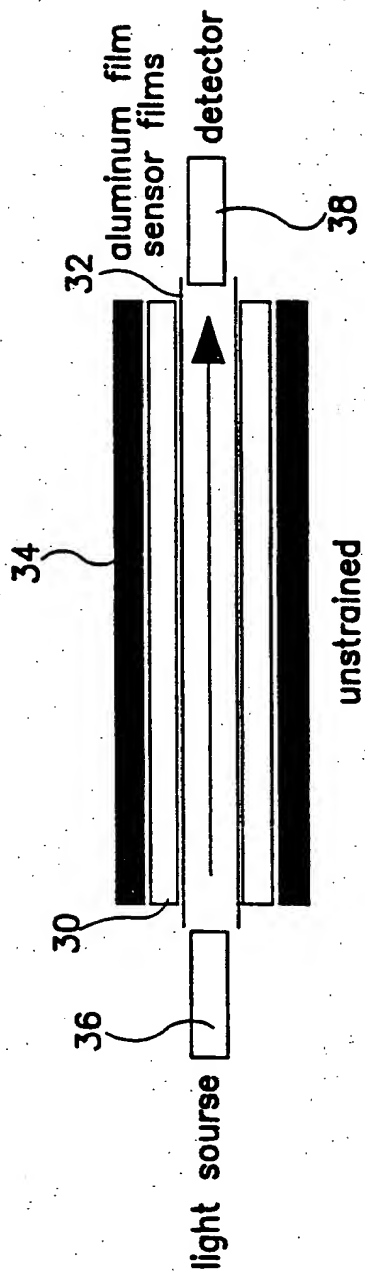


FIG. 2a

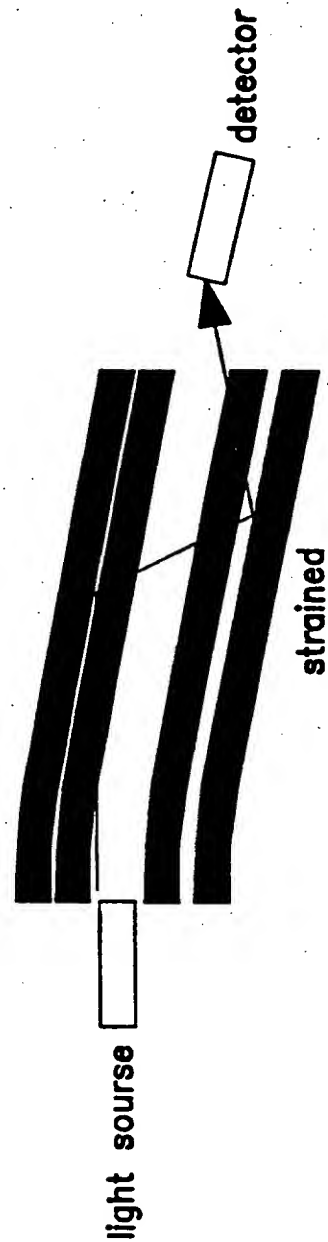
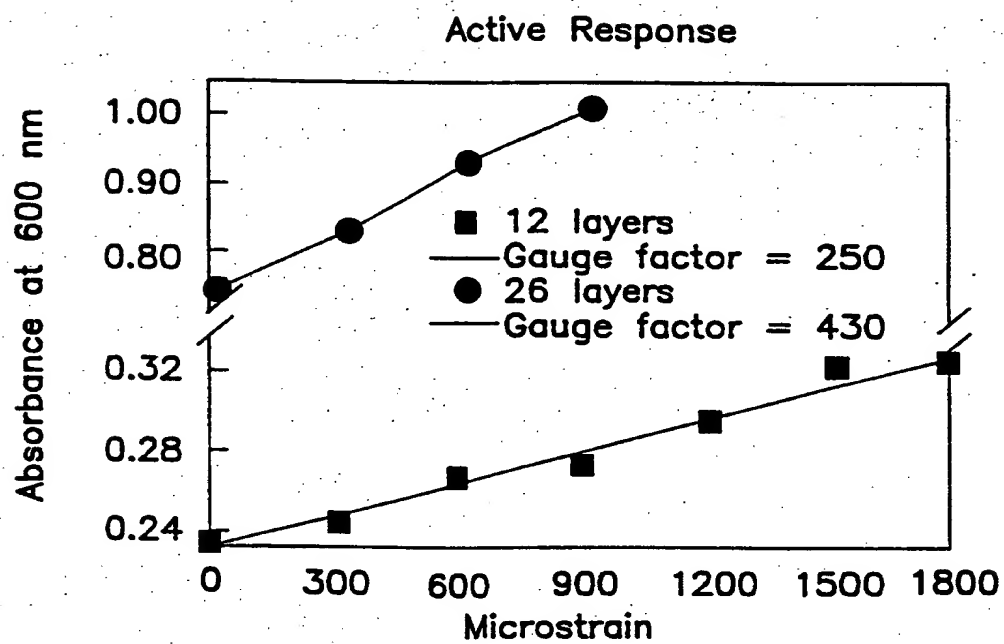


FIG. 2b

**FIG. 3**

4/5

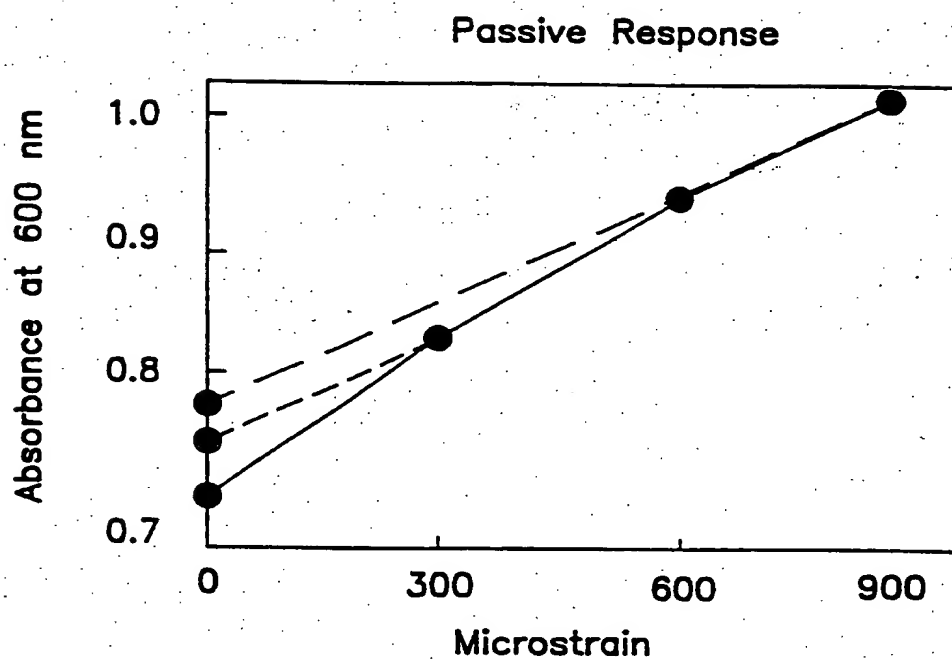


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/19601

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01B 09/02

US CL :356/357

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/357, 359, 360

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

US PTO APS: thickness, interference, polyfilm

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,120,966 A (KONDO) 9 JUNE 1992 (09.06.92), see entire document	1-16



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

30 SEPTEMBER 1999

Date of mailing of the international search report

18 OCT 1999

Name and mailing address of the ISA/US
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Box PCT
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SERIAL NO. Unknown

EULER, William B. et al.
APPLICANT

Unknown

GROUP

Unknown

EXAMINER

February 14, 2001
FILING DATE

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

U.S. PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
	AA	5,120,966	06/09/92	Kondo			
	AB						
	AC						
	AD						
	AE						
	AF						
	AG						
	AH						

FOREIGN PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION YES NO
	AI						
	AJ						
	AK						
	AL						
	AM						

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

EXAMINER INITIAL		
	AN	
	AO	

EXAMINER

DATE CONSIDERED

EXAMINER:

Initial if citation considered, whether or not citation is in conformance with MPEP 609; draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.



US 5,120,966A

United States Patent [19][11] Patent Number: **5,120,966****Kondo**[45] Date of Patent: * **Jun. 9, 1992****[54] METHOD OF AND APPARATUS FOR MEASURING FILM THICKNESS**[75] Inventor: **Noriyuki Kondo, Kyoto, Japan**[73] Assignee: **Dainippon Screen Mfg. Co., Ltd., Kyoto, Japan**

[*] Notice: The portion of the term of this patent subsequent to Jan. 15, 2008 has been disclaimed.

[21] Appl. No.: **652,358**[22] Filed: **Feb. 6, 1991****Related U.S. Application Data**

[63] Continuation of Ser. No. 377,395, Jul. 10, 1989. abandoned.

[30] Foreign Application Priority Data

Jul. 12, 1988 [JP] Japan 63-174361

[51] Int. Cl.⁵ **G01N 21/55; G01B 11/06**[52] U.S. Cl. **250/372; 250/341; 356/381; 356/357**[58] Field of Search **250/372, 341; 356/381, 356/357****[56] References Cited****U.S. PATENT DOCUMENTS**

2,929,257	2/1960	Friedman	
3,565,531	2/1971	Kane et al.	356/381
4,555,767	11/1985	Case et al.	356/381
4,623,254	11/1986	Imose	356/381
4,859,064	8/1989	Messerschmidt et al.	250/341
4,899,055	2/1990	Adams	250/372
4,984,894	1/1991	Kondo	356/357

Primary Examiner—Carolyn E. Fields*Assistant Examiner*—Drew A. Dunn*Attorney, Agent, or Firm*—Lowe, Price, Leblanc & Becker**[57] ABSTRACT**

Light in the ultraviolet region is applied toward a transparent thin film of an object sample to measure energy of light reflected by the object sample. On the basis of the measured energy value, the thickness of the transparent thin film on the object sample can thus be correctly measured even if the film thickness is not more than 10 nm. In the preferred embodiment, an optical system is included to enable monitoring of a position of the thin transparent film. In one aspect of the invention visible light reflected from the transparent film is used to form an image to facilitate such monitoring.

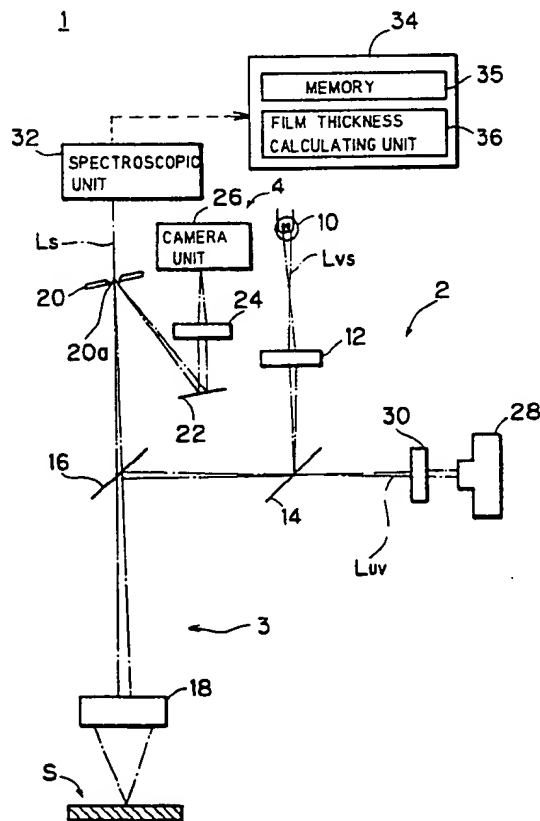
3 Claims, 6 Drawing Sheets

FIG. 1

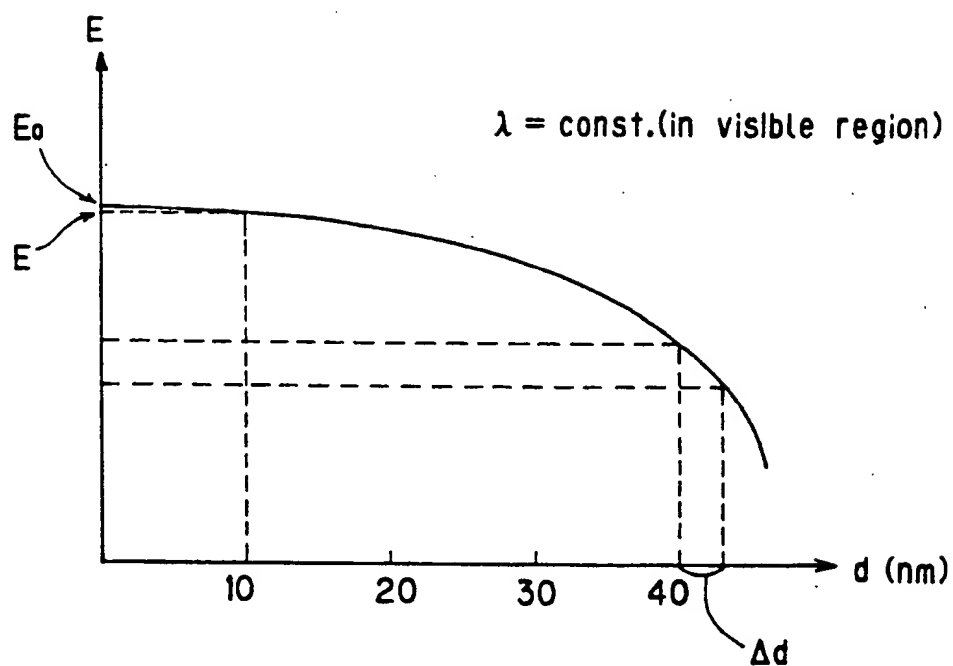


FIG. 2

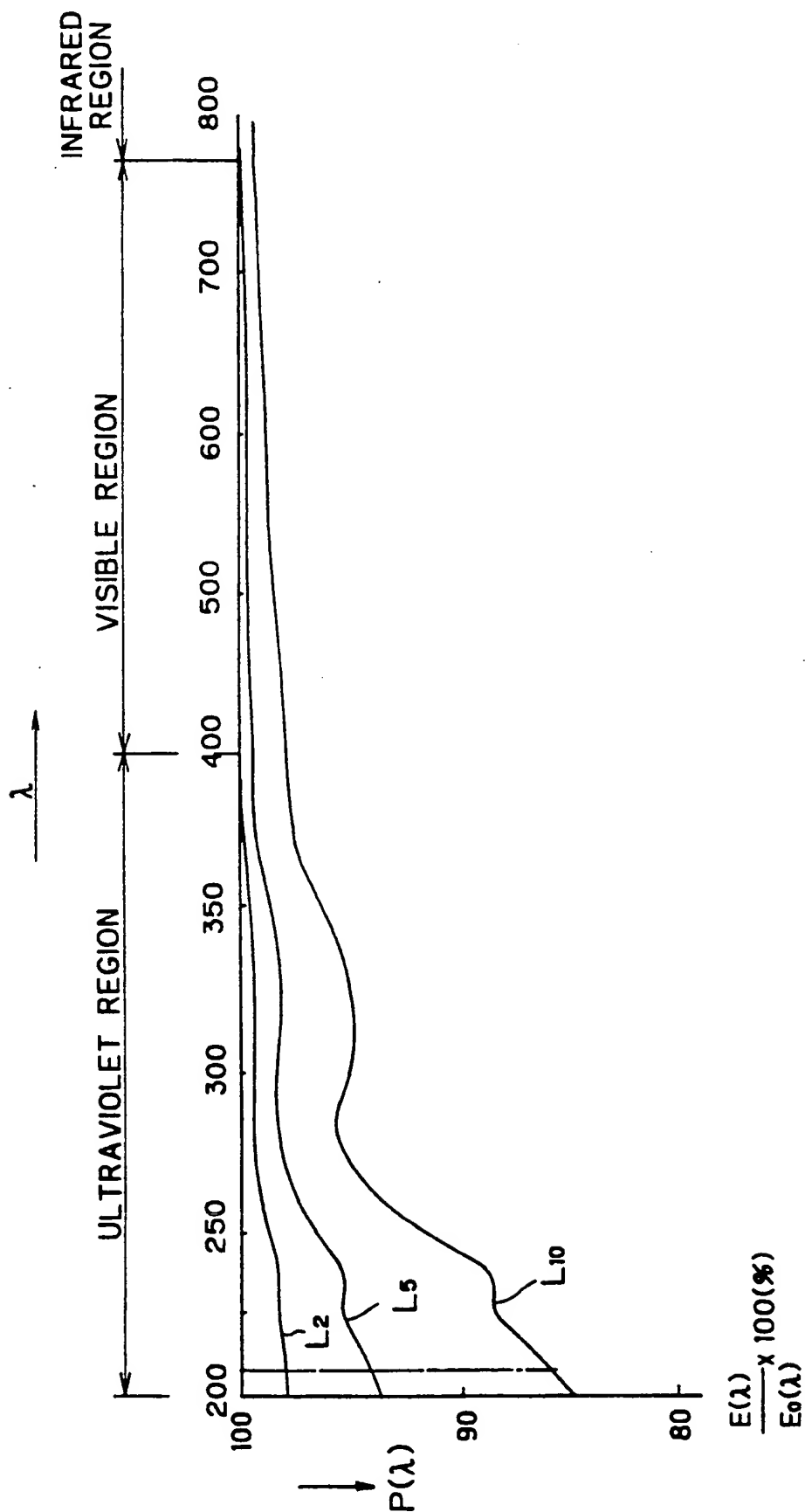


FIG. 3

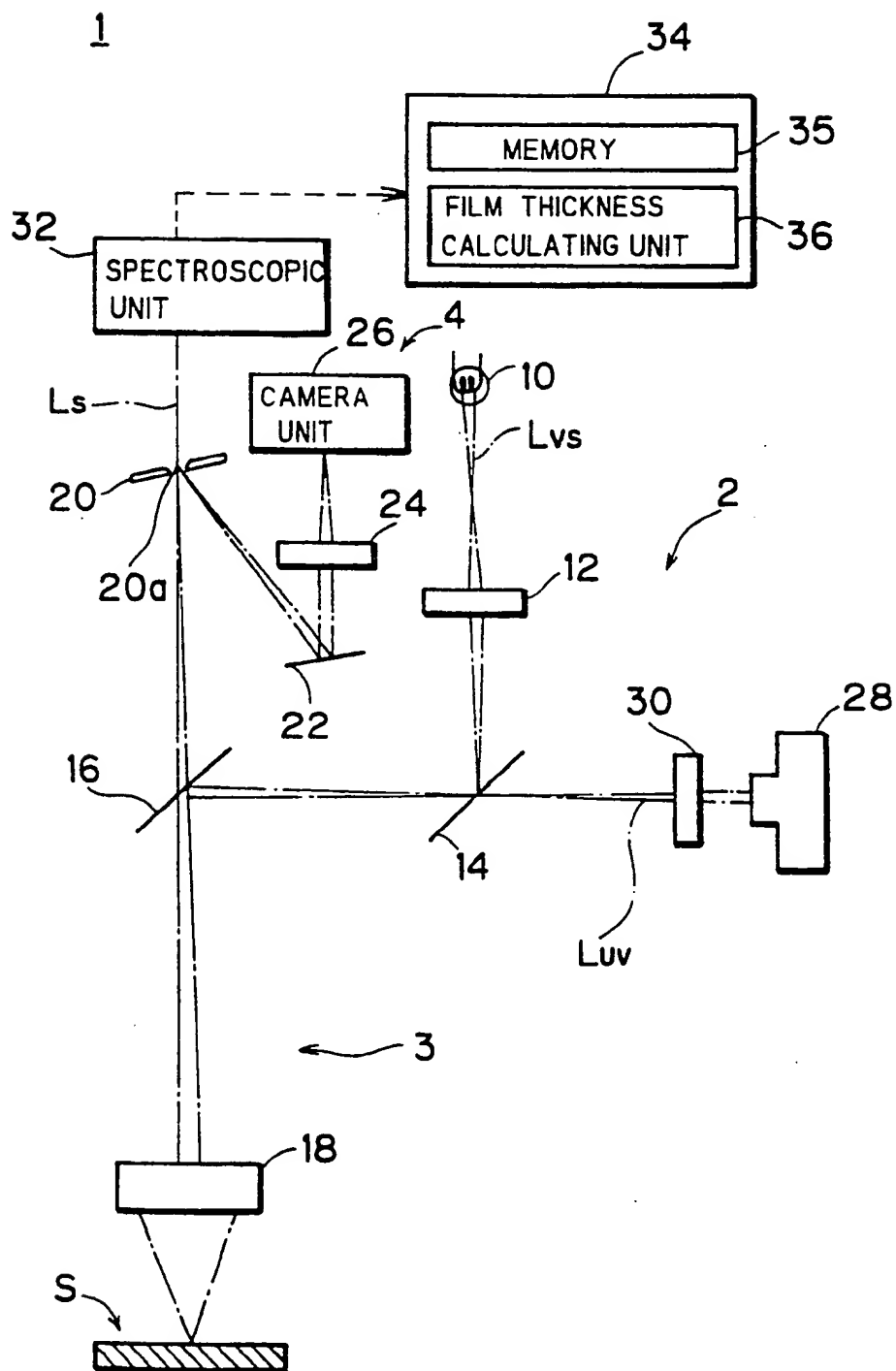


FIG. 4

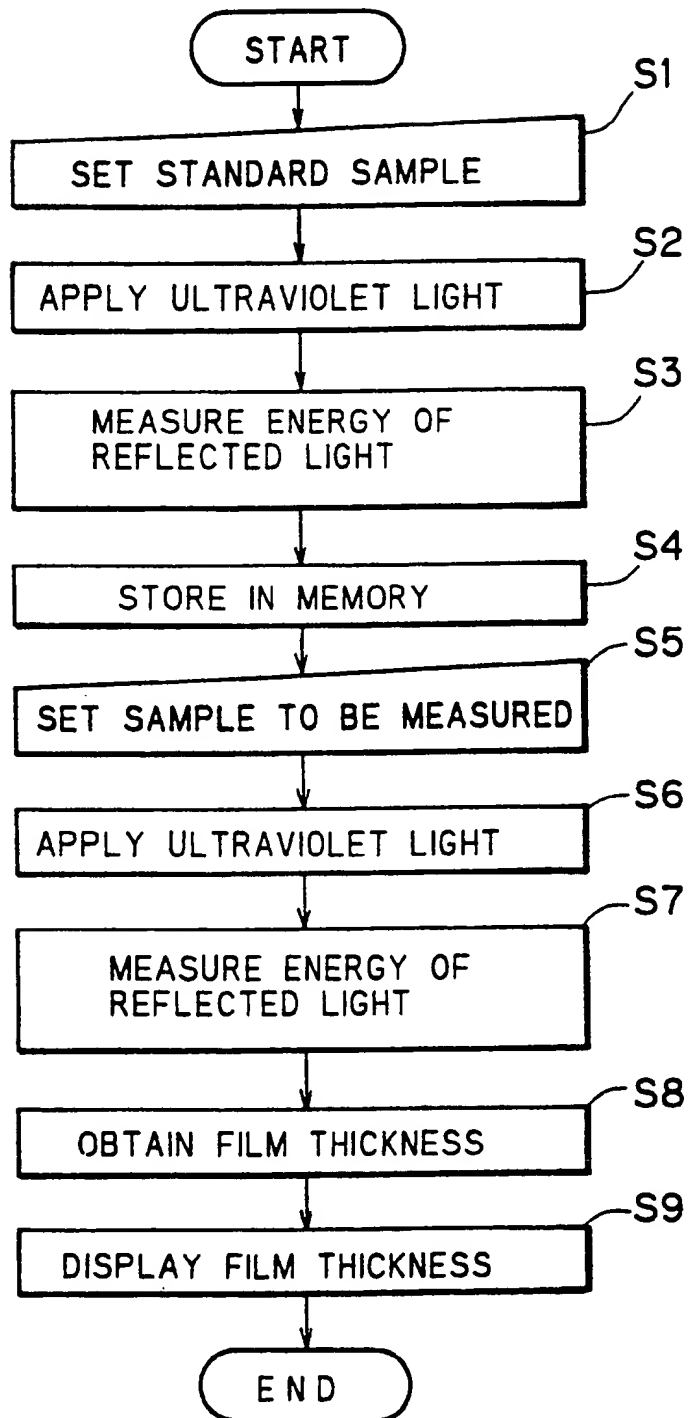


FIG. 5

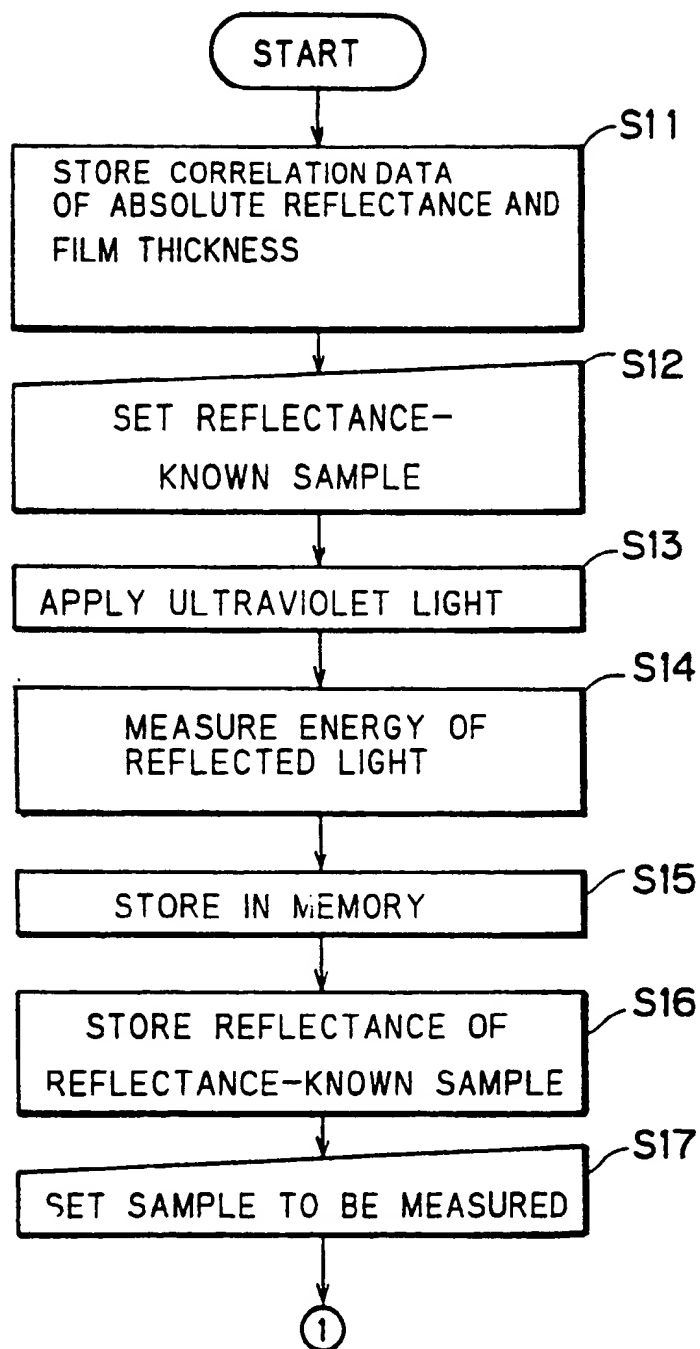
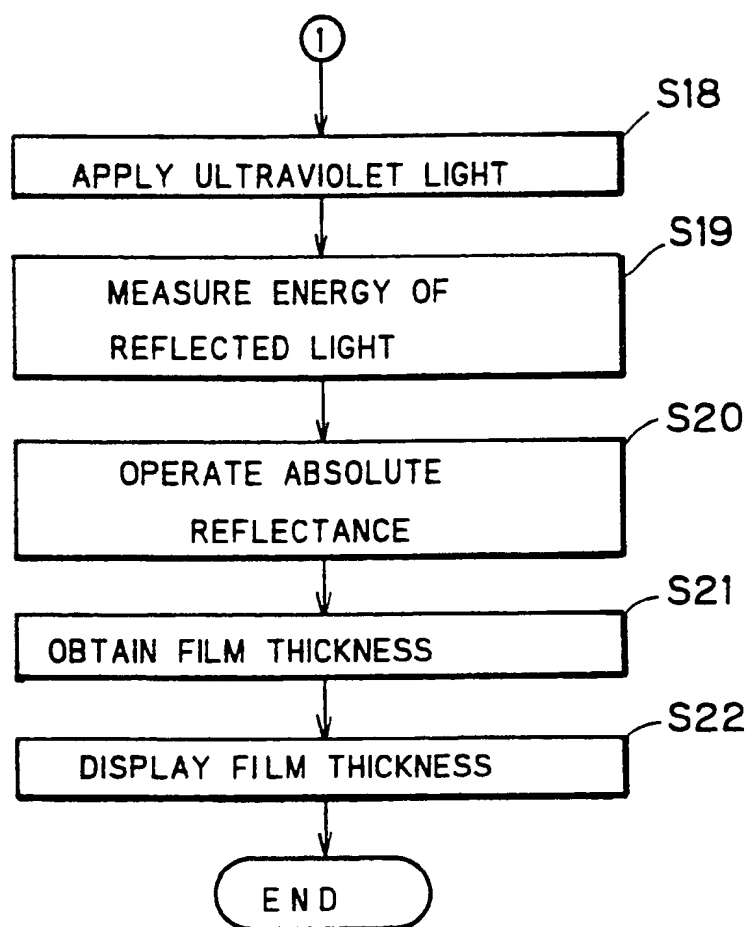


FIG. 5 (CONT.)



METHOD OF AND APPARATUS FOR MEASURING FILM THICKNESS

This application is a continuation of application Ser. No. 07/377,395 filed Jul. 10, 1989, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and an apparatus for correctly measuring optically the thickness of a transparent thin film formed on a substrate.

2. Background of the Prior Art

In a film thickness inspection of a semiconductor manufacturing process or the like, it is necessary to measure the thickness of a silicon oxide film which is formed on a silicon substrate, for example, in a non-contact manner. In order to measure such film thickness, generally employed are a method (hereinafter referred to as the "polarization analyzing system") of measuring a change in a polarized state of reflected light and obtaining the film thickness from such change and another method (hereinafter referred to as the "reflected light energy measuring system") of irradiating a sample to be measured with light for measuring the energy of light reflected by the sample to thereby obtain the film thickness from the energy.

In the polarization analyzing system, light is applied to a sample obliquely from above for measuring the thickness of a transparent thin film formed on the sample. Thereafter, detected are change in a polarized state of light reflected by the sample to be measured (i.e., change in relative phase shift between the P wave, which is a vibration component parallel to the plane of incidence, and the S wave, which is a vibration component perpendicular to the plane of incidence) and change in the amplitude ratio between the waves. Further, the thickness of the transparent thin film is obtained on the basis of the detected change. This polarization analyzing system is applied to an ellipsometer, for example, so that the thickness of a thin film formed on a sample to be measured can be accurately measured by the ellipsometer in a non-contact manner even if the film thickness is not more than 10 nm. However, it is difficult to measure a region to be measured while limiting the same in a narrow range. Thus, the reflected light energy measuring system, which is described below, is generally employed in a semiconductor manufacturing process.

When light is applied to a sample to be measured, light reflected by the surface of a transparent thin film formed on the sample interferes with that reflected by the surface of a substrate of the sample, whereby constant relation holds between the energy of the reflected light and the thickness of the transparent thin film. In reflected light energy measuring system, the thickness of the thin film is obtained on the basis of such relation.

In more concrete terms, the thickness of the transparent thin film is obtained as follows: First, samples (hereinafter referred to as "first standard samples") provided with transparent thin films having different thickness values are prepared in order to obtain correlation data of energy of reflected light and thickness values of the transparent thin films. Optical constants of the transparent thin films and substrates of the first standard samples are identical to those of a sample to be measured, and the thickness values of the transparent thin films of the first standard samples are known, respectively. Visible

light is applied to the first standard samples to measure energy of light reflected by the surface of the standard samples, to thereby obtain correlation data of the energy of the reflected light and the thickness values of the transparent thin films. Thus, preparation is completed. Then, visible light is applied to the sample to be measured, in order to measure energy of light reflected by the sample to be measured. Finally, the thickness of a thin film formed on this sample is obtained on the basis of the measured values and the correlation data.

As understood from the above, the reflected light energy must be significantly changed in response to change in film thickness, so that the film thickness can be correctly measured by the reflected light energy measuring system. In general, most of thin films formed on semiconductor substrates are at least 40 nm in thickness, and the reflected light energy is significantly changed even if the amount Δd of change in film thickness is very small. Thus, it has been possible to measure the thickness of such a thin film to a relatively high accuracy by the reflected light energy measuring system.

The thickness of a thin film has been reduced with recent improvement in semiconductor manufacturing technique, and it has been increasingly demanded to accurately measure such film thickness also within a range of not more than 10 nm. However, it is impossible to correctly measure film thickness of not more than 10 nm by the reflected light energy measuring system. The reason for this is that energy of light reflected by a thin film of not more than 10 nm in thickness is approximate to energy E_0 of light reflected by a sample (hereinafter referred to as "second standard sample") which is provided with no transparent thin film. In other words, energy of reflected light is substantially constant within a range of 0 to 10 nm in thickness. In more concrete terms, the energy of reflected light is theoretically provided as E in the case of film thickness of 10 nm, for example, as shown in FIG. 1, while actually measured energy of the reflected light includes a measurement error, to thereby be not identical to the theoretical value E . As understood from FIG. 1, variation in energy with respect to change in film thickness is small around film thickness of 10 nm, particularly that of not more than 10 nm. Therefore, film thickness obtained on the basis of the energy value including the aforementioned measurement error may significantly differ from the true film thickness.

SUMMARY OF THE INVENTION

The present invention is directed to a method of and an apparatus for measuring the thickness of a transparent thin film of an object sample to be measured which comprises a substrate and the transparent thin film provided on the substrate.

According to the present invention, the method includes: a first step of applying light in the ultraviolet region, having a wavelength less than 240 nm, toward the transparent thin film to measure energy of light reflected by the object sample; and second step of obtaining the thickness of the transparent thin film on the basis of the energy measured in the first step.

The apparatus comprises: (a) means for applying light in the ultraviolet region toward a transparent thin film on the sample; (b) means for measuring energy of light reflected by the object sample; (c) means for obtaining

the thickness of the transparent thin film on the basis of the energy value measured by the measuring means.

Accordingly, an object of the present invention is to provide a method of and an apparatus for correctly measuring the thickness of a transparent thin film of the object sample even if the thickness thereof is not more than 10 nm.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates relations between energy of visible light reflected by an object sample and the thickness of a transparent thin film on the object sample;

FIG. 2 illustrates relations between reflected light energy percentage $P(\lambda)$ and wavelength λ ;

FIG. 3 is a schematic block diagram showing a film thickness measuring apparatus according to a preferred embodiment of the present invention;

FIG. 4 is a flow chart showing a method of measuring film thickness by the film thickness measuring apparatus shown in FIG. 3; and

FIG. 5 is a flow chart showing the film thickness measuring method according to a second embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. Principle of the Invention

In order to solve the aforementioned technical problem, various researches have been made to obtain the results shown in FIG. 2. FIG. 2 illustrates relations between reflected light energy percentage $P(\lambda)$ and wavelength λ . In more concrete terms, the relations have been obtained in the following manner: Light was applied to a silicon substrate to obtain energy $E_0(\lambda)$ of light reflected by the silicon substrate, while light was also applied to samples comprising silicon substrates and SiO_2 films of prescribed thickness values (2 nm, 5 nm and 10 nm) provided on the silicon substrates, respectively to obtain values of energy $E(\lambda)$ of light reflected by the respective samples. Then, the reflected light energy percentage $P(\lambda)$ was obtained on the basis of the following expression:

$$P(\lambda) = \frac{E(\lambda)}{E_0(\lambda)} \cdot 100 \quad (1)$$

Solid lines L_2 , L_5 and L_{10} in FIG. 2 show relations between the reflected light energy percentage $P(\lambda)$ and the wavelength λ in the case that the SiO_2 films of 2 nm, 5 nm and 10 nm in thickness are formed on the silicon substrates, respectively.

Table 1 lists some of values of the reflected light energy percentage $P(\lambda)$ with respect to the wavelength λ obtained in the aforementioned manner.

TABLE 1

thickness value (nm)	λ (nm)					
	207	256	316	407	500	596
2	97.93	98.97	99.41	99.87	99.91	99.95
5	93.98	97.00	98.12	99.34	99.54	99.67
10	85.30	92.53	94.92	97.66	98.24	98.72

TABLE 1-continued

thickness value (nm)	λ (nm)					
	207	256	316	407	500	596
20	66.41	79.70	84.56	91.25	93.19	94.95

In order to obtain the aforementioned relations, optical constants of silicon and SiO_2 were determined on the basis of "Handbook of Optical Constants of Solids".

Analyzing FIG. 2 and Table 1, the following first to third phenomena have been ascertained:

FIRST PHENOMENON

In the visible and infrared regions ($\lambda=400$ to 900 nm), the reflected light energy percentage $P(\lambda)$ is reduced as the wavelength λ is shortened (hereinafter referred to as "first phenomenon") under the condition that the film thickness is constant. Noting the solid line L_{10} in FIG. 2, for example, the reflected light energy percentage $P(596)$ with respect to the wavelength of 596 nm is 98.72%, while the reflected light energy percentage $P(\lambda)$ is reduced as the wavelength λ is shortened such that the reflected light energy percentage $P(407)$ with respect to the wavelength of 407 nm is 97.66%, as shown in FIG. 2 and Table 1. As understood from FIG. 2, detection accuracy for the film thickness is advantageously improved as the wavelength of light is reduced within such a wavelength range. However, since variation in reflected light energy percentage $P(\lambda)$ with respect to that in wavelength λ is small, it is difficult to attain the object of the present invention through the first phenomenon in practice.

SECOND PHENOMENON

In the ultraviolet region ($\lambda=200$ to 400 nm), the reflected light energy percentage $P(\lambda)$ is extremely reduced as the wavelength λ is shortened under the condition that the film thickness is constant. It means that the energy $E(\lambda)$ is remarkably reduced as compared with the energy $E_0(\lambda)$ (this phenomenon is hereinafter referred to as "second phenomenon"). As understood from the expression (1). Noting the solid line L_{10} in FIG. 2, for example, the reflected light energy percentage $P(407)$ with respect to the wavelength of 407 nm is 97.66%, while the reflected light energy percentage $P(207)$ with respect to the wavelength of 207 nm is 85.30%, as shown in FIG. 2 and Table 1.

In the ultraviolet region ($\lambda=200$ to 400 nm), therefore, the energy $E(\lambda)$ of the light reflected by the samples provided with SiO_2 films of not more than 10 nm in thickness is remarkably reduced as compared with the energy $E_0(\lambda)$ of the light reflected by the silicon substrates.

THIRD PHENOMENON

In the ultraviolet region ($\lambda=200$ to 400 nm), the reflected light energy percentage $P(\lambda)$ is extremely changed as the SiO_2 films are increased in thickness (this phenomenon is hereinafter referred to as "third phenomenon") under the condition that the wavelength λ is constant as one-dot chain line in FIG. 2 shows.

This can be easily understood also from Table 1. Assuming that the wavelength λ is 596 nm, for example, reflected light energy percentage $P_{(at\ 2\ nm)}$ is 99.95% when the film thickness is 2 nm, while reflected light energy percentage $P_{(at\ 10\ nm)}$ is 98.72% when the film thickness is 10 nm. Therefore, the reflected light energy

percentage $P(\lambda)$ is changed by about 1% under the aforementioned condition. Assuming that the wavelength λ is 207 nm, on the other hand, the reflected light energy percentage $P_{(at\ 2\ nm)}$ is 97.93% and the reflected light energy percentage $P_{(at\ 10\ nm)}$ is 85.30%. Thus, the third phenomenon is clearly understood also from Table 1.

While the above description has been made on the relation between the reflected light energy percentage $P(\lambda)$ and the film thickness, phenomena similar to the above are recognized also between the energy $E(\lambda)$ of the reflected light and the film thickness when the wavelength λ is constant. That is, values $P_1(\lambda_1)$, $P_2(\lambda_1)$, ... of reflected light energy percentage with respect to values d_1 , d_2 , ... of film thickness under the condition that the wavelength is constant ($\lambda = \lambda_1$) are respectively obtained as follows:

$$\left. \begin{aligned} P_1(\lambda_1) &= \frac{E_1(\lambda_1)}{E_0(\lambda_1)} \cdot 100 \\ P_2(\lambda_1) &= \frac{E_2(\lambda_1)}{E_0(\lambda_1)} \cdot 100 \\ &\vdots \\ &\vdots \end{aligned} \right\}$$

As understood from the expressions (2), energy $E_0(\lambda_1)$ of the light reflected by the silicon substrates is constant, and hence the energy $E(\lambda)$ of the reflected light is extremely changed as the SiO_2 films are increased in thickness, similarly to the third phenomenon.

The aforementioned second and third phenomena were also observed when the thickness values of the SiO_2 films were at least 10 nm. While the above description has been made with respect to the case where the SiO_2 films were formed on the silicon substrates, similar phenomena were also recognized in other case.

Table 2 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to silicon substrates provided with Si_3N_4 films.

TABLE 2

thickness value (nm)	λ (nm)					
	207	256	316	407	500	596
2	89.84	96.54	98.23	99.62	99.78	99.86
5	66.57	89.29	94.34	98.23	98.84	99.20
10	18.00	70.26	84.25	93.73	95.64	96.95
20	62.48	29.22	48.73	76.00	83.10	87.97

Table 3 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to GaAs substrates provided with SiO_2 films.

TABLE 3

thickness value (nm)	λ (nm)					
	207	256	316	407	550	596
2	96.68	98.91	98.80	99.45	99.80	99.87
5	90.54	96.69	96.38	98.32	99.26	99.48
10	77.64	91.43	90.78	95.63	97.70	98.34
20	52.69	75.46	74.14	87.23	92.17	94.20

Table 4 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to GaAs substrates provided with Si_3N_4 films.

TABLE 4

thickness value (nm)	λ (nm)					
	207	256	316	407	550	596
2	84.88	96.41	96.44	98.45	99.47	99.65
5	54.02	88.73	89.39	95.28	98.07	98.70
10	6.22	68.61	73.01	87.68	94.12	95.92
20	67.65	15.23	27.66	63.37	80.07	85.93

Table 5 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to Al substrates provided with SiO_2 films.

TABLE 5

thickness value (nm)	λ (nm)					
	207	256	316	407	550	596
2	99.50	99.69	99.8	99.89	99.92	99.95
5	98.56	99.12	99.45	99.68	99.79	99.84
10	96.50	97.86	98.67	99.23	99.48	99.62
20	92.81	94.49	96.44	97.93	98.65	98.98

Table 6 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to Al substrates provided with Si_3N_4 films.

TABLE 6

thickness value (nm)	λ (nm)					
	207	256	316	407	550	596
2	95.08	98.90	99.40	99.67	97.76	99.84
5	80.87	96.52	98.19	99.02	99.37	99.53
10	48.08	89.79	95.10	97.53	98.46	98.87
20	76.27	82.39	84.15	92.18	95.45	96.81

Table 7 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to Cr substrates provided with SiO_2 films.

TABLE 7

thickness value (nm)	λ (nm)					
	207	256	316	407	500	596
2	94.26	97.35	98.75	99.37	99.61	99.67
5	84.43	92.75	96.57	98.26	98.92	99.13
10	66.49	83.68	92.09	95.98	97.47	97.97
20	45.70	64.84	80.61	89.83	93.48	94.82

Table 8 shows relations between reflected light energy percentage $P(\lambda)$ and wavelength λ with respect to Cr substrates provided with Si_3N_4 films.

TABLE 8

thickness value (nm)	λ (nm)					
	207	256	316	407	500	596
2	74.20	91.04	96.19	98.18	98.91	99.12
5	31.50	74.17	89.03	94.84	96.92	97.55
10	9.08	41.43	72.90	87.50	92.59	94.21
20	104.27	48.31	36.43	65.14	79.45	84.48

Procedures for deriving the values shown in these Tables are identical to that of Table 1. Optical constants of GaAs and Si_3N_4 are determined on the basis of "Handbook of Optical Constants of Solids" and that of Al is determined on the basis of "Physics Daten Physics Data, Optical Properties of Metals 1981 Nr. 18-2", while that of Cr is determined on the basis of "Physics Daten Physics Data, Optical Properties of Metals 1981 Nr. 18-1".

As hereinabove described, the energy $E(\lambda)$ of light reflected by a sample to be measured is remarkably reduced as compared with the energy $E_0(\lambda)$ when light of the ultraviolet region is applied to the sample even if

the film thickness is not more than 10 nm, while the energy $E(\lambda)$ of the reflected light is extremely changed in response to slight change in thickness within the range of the film thickness of not more than 10 nm. Therefore, the thickness of a transparent thin film can be correctly measured through the light of the ultraviolet region even if the film thickness is not more than 10 nm, in addition to the case of film thickness of at least 10 nm.

B. The First Preferred Embodiment

FIG. 3 is a schematic block diagram showing a film thickness measuring apparatus 1 according to a preferred embodiment of the present invention. As shown in FIG. 3, the film thickness measuring apparatus 1 is formed by an illumination optical system 2, a microscopic optical system 3, a reflecting mirror 20, a spectroscopic unit 32, a monitoring optical system 4, an arithmetic unit 34 and a control unit (not shown) for controlling the entire apparatus.

The illumination optical system 2 comprises a light source 10 such as a halogen lamp, for example, emitting visible light L_V , a lens 12 and a shutter mirror 14 which is vertically reciprocable with respect to the plane of the figure, so that visible light L_V outgoing from the light source 10 is guided to the microscopic optical system 3 through the lens 12 and the shutter mirror 14. The illumination optical system 2 also comprises a light source 28 emitting ultraviolet light and a lens 30, so that ultraviolet light L_{UV} can be guided to the microscopic optical system 3 in place of the visible light L_V .

The light source 28 may apply light of a specific ultraviolet region, and can be prepared by a deuterium lamp, a mercury lamp, an ultraviolet laser irradiator, a xenon lamp or the like.

The microscopic optical system 3 is formed by a half mirror 16 and a mirror type image formation element 18.

Therefore, when the shutter mirror 14 is on an optical axis as shown in FIG. 3, the visible light L_V outgoing from the light source 10 is applied to the surface of an object sample S to be measured through the lens 12, the shutter mirror 14, the half mirror 16 and the mirror type image formation element 18. When the shutter mirror 14 is evacuated from the optical axis, on the other hand, the ultraviolet light L_{UV} outgoing from the light source 28 is applied to the surface of the object sample S through the lens 30, the half mirror 16 and the mirror type image formation element 18.

A beam reflected by the surface of the object sample S is enlargedly imaged in a position close to the reflecting mirror 20 through the image formation element 18 and the half mirror 16.

The reflecting mirror 20 is provided with a pinhole 20a. Within the reflected beam, therefore, reflected light L_S passing through the pinhole 20a is incorporated in the spectroscopic unit 32.

The spectroscopic unit 32 is formed by a diffraction grating (not shown) for separating the reflected light L_S into its spectral components and an optical detector (not shown) for detecting the spectrum. Therefore, the spectroscopic unit 32 detects the spectrum of the light L_S incorporated therein, and supplies a signal corresponding to the spectrum of the light L_S to the arithmetic unit 34. The arithmetic unit 34 is formed by a memory 35 and a film thickness calculating unit 36, to calculate the film thickness of the object sample S on the basis of the signal outputted from the spectroscopic unit 32.

Within the reflected beam, on the other hand, light reflected by the reflecting mirror 20 is incident upon the monitoring optical system 4, and imaged in a camera unit 26 through a mirror 22 and the image formation lens 24. Thus, the camera unit 26 picks up an enlarged image of the surface of the object sample S and projects the same on a CRT (not shown). Confirmation of the position of measurement and focusing of optical system of the apparatus 1 can be performed on the basis of the enlarged image. Although visible light is employed in order to confirm the position for measuring the film thickness of the object sample S and to focus the optical system in the aforementioned apparatus, the surface of the object sample S can also be observed through ultraviolet light. Thus, the light source 10, the lens 12 and the shutter mirror 14 are optional elements of the present invention.

FIG. 4 is a flow chart showing a method of measuring film thickness by the film thickness measuring apparatus 1. A plurality of first standard samples, which comprise substrates and transparent thin films whose optical constants are identical to those of the object sample with known thickness values of the transparent thin films, are prepared. Energy levels with respect to specific wavelengths of light reflected by the first standard samples in the ultraviolet region are measured, to thereby obtain correlation data of energy levels $E(\lambda)$ of the reflected light and thickness values d of the transparent thin films previous to film thickness measurement by the film thickness measuring apparatus 1. Schematically stated, the first one of the first standard samples is set in a prescribed position of the film thickness measuring apparatus 1 (step S1) and then ultraviolet light L_{UV} outgoing from the light source 28 is applied to the first standard sample (step S2), to thereby measure the energy $E(\lambda)$ of the light reflected by the first standard sample by the spectroscopic unit 32 (step S3). The data corresponding to the energy value $E(\lambda)$ is stored in the memory 35 in correspondence to the thickness value d (step S4). Thereafter the steps S1 to S4 are sequentially repeated with respect to the plurality of first standard samples having different thickness values, to thereby store correlation data of the energy values E and the thickness value d .

The data are so stored in the memory 35 that, when the energy of the light reflected by one sample is read as an address, the thickness value of the transparent thin film of the sample is outputted. However, the method of storing the data is not restricted to this.

Upon completion of the aforementioned prepreparation, the film thickness of the object sample S is measured as follows: An operator sets the object sample S in a prescribed position as shown in FIG. 3 (step S5). At this time, the light source 10 is turned on in accordance with a command from the operator, so that an image of the surface of the object sample S picked up by the camera unit 26 is projected on the CRT. The operator can confirm the position of the object sample S and focuses the optical system of the apparatus 1 on the basis of the image projected on the CRT, to thereby correctly specify the position of measurement.

Thereafter the operator supplies a measurement start command to the control unit, so that steps S6 to S9 are executed in response to a command from the control unit. That is, the light source 28 is turned on and the shutter mirror 14 is evacuated from the optical axis of the ultraviolet light L_{UV} , so that the ultraviolet light

Light 9 outgoing from the light source 28 is applied to the surface of the object sample S (step S6).

The wavelength of the light applied to the object sample S must be identical to that of the light applied to the first standard samples at the step S2. The wavelength, which may be arbitrarily determined so far as the same is within the ultraviolet region, is preferably within a range of 180 to 240 nm in view of the properties of the light source 28 etc.

The ultraviolet light applied to the surface of the object sample S is reflected by the said surface, and the spectroscopic unit 32 measures energy $E(\lambda)$ of the reflected light L_S (step S7). Thus, a signal relating to the energy $E(\lambda)$ of the reflected light L_S detected by the spectroscopic unit 32 is supplied to the arithmetic unit 34. Film thickness calculating unit 36 provided in the arithmetic unit 34 obtains the thickness of the transparent thin film formed on the object sample S on the basis of the signal relating to the energy $E(\lambda)$ (step S8). That is, when an address corresponding to the signal supplied to the arithmetic unit 34 is present in the memory 35, a film thickness value stored in the said address is read and displayed on a display unit (not shown) as the thickness of the transparent thin film (step S9). If there is no corresponding address, on the other hand, an address approximate to the energy value measured at the step S7 is accessed to read the film thickness value stored in the said address, and interpolation operation is made in the film thickness calculating unit 36 so that the result of the operation is displayed on the display unit as the thickness of the transparent thin film formed on the object sample S (step S9). Or, only an address most approximate to the value actually measured at the step S7 may be accessed to assume the film thickness value stored in the said address as the thickness of the transparent thin film. In this case, however, measurement accuracy is slightly inferior to that in the aforementioned interpolation operation case.

According to the first embodiment of the present invention, as hereinabove described, the energy of the reflected light is measured through the light of the ultraviolet region, whereby the thickness of the transparent thin film can be correctly measured even if the thickness is not more than 10 nm, in addition to the case of the thickness of at least 10 nm.

Since the thickness of the thin film is measured in the above manner in the first embodiment, the optical constants of the transparent thin film and the substrate of the object sample S may be unknown.

The thickness values of the transparent thin films formed on the standard first samples must be known and may be previously actually measured by an ellipsometer, for example. However, when the thickness values of the transparent thin films formed on the first standard samples are previously measured by the ellipsometer, it is difficult to specify measured positions of the first standard samples as hereinabove described, and hence the standard samples must be uniformly provided with the transparent thin films over considerably wide ranges. On the other hand, the transparent thin film of the object sample S may be formed on a narrow specific position of the object sample S. This is because the position of the object sample S can be easily and correctly specified as obvious from the fact that the optical axis of the camera unit 26 for picking up the image of the object sample S is arranged to coincide with the optical axis of the optical system (image formation element 18) for measuring the energy values of the re-

flected light in the apparatus for carrying out the inventive method, as shown in FIG. 3.

Although the first standard samples are prepared to carry out the steps S1 to S4 for obtaining correlation between the film thickness values and the energy values of the reflected light in the first embodiment, such correlation may be obtained by another method. For example, the correlation may be calculated by arithmetic processing on the basis of the optical constants of the object sample S, the properties of the light source 28 and the like, to be stored in the memory 35.

C. The Second Preferred Embodiment

The absolute reflectance R_S of an object sample S to be measured is univocally determined upon provision of a refractive index n_0 and an absorption coefficient k_0 of an incident-side medium (air in general, since film thickness is measured in the atmospheric air), a refractive index n_1 and an absorption coefficient k_1 of a transparent thin film, a refractive index n_2 and an absorption coefficient k_2 of the substrate, wavelength λ and an incident angle ϕ of illumination light and thickness d_x of the transparent thin film. Therefore, when these values n_0 , n_1 , n_2 , k_0 , k_1 , k_2 , λ and ϕ are specified, the thickness d_x can be obtained on the basis of the value of the absolute reflectance R_S . Although it is not easy to actually measure the absolute reflectance R_S of the object sample S, the absolute reflectance R_S can be calculated from the energy of light reflected by the object sample S. Thus, the thickness of the thin film formed on the object sample S can be measured on the basis of the aforementioned principle of film thickness measurement.

A film thickness measuring apparatus according to a second embodiment of the present invention has a film thickness calculating unit which is different from that of the first embodiment, and carries out film thickness measurement while controlling the overall apparatus as hereinafter described by a control unit. Structure other than the film thickness calculating unit is identical to that of the first embodiment. Therefore, the film thickness measuring apparatus according to the second embodiment is not shown in the figure but a film thickness measuring method according to the second embodiment is described with numerals identical to those in the first embodiment.

FIG. 5 is a flow chart showing the film thickness measuring method according to the second embodiment. First, as preparation for measurement of thickness of a transparent thin film provided in the object sample, an operator inputs correlation data of the absolute reflectance R_S and the film thickness d_x on the basis of literature such as Handbook of Optical Constants of Solids, Academic Press, for example, through a keyboard (not shown) to store the same in a memory 35. Similarly to the first embodiment, the correlation data are so stored that corresponding film thickness is outputted upon addressing with the absolute reflectance R_S .

As the preparation, further, the operator sets a sample P (hereinafter referred to as "reflectance-known sample"), at least the absolute reflectance of which is known, in the measuring apparatus (step S12). Preferably the absolute reflectance of the reflectance-known sample P, which may be arbitrarily prepared so far as its absolute reflectance is clear, is not extremely different from that of the object sample S. Thus, the reflectance-known sample P may be prepared from the same material as the substrate of the object sample S. Ultraviolet

light L_{UV} is applied to the sample S (step S13), to measure energy E_P of a specific wavelength of light reflected by the reflectance-known sample P in the ultraviolet region (step S14). The measured energy E_P is stored in the memory 35 (step S15). The operator further inputs the absolute reflectance R_P of the reflectance-known sample P through the keyboard to store the same in the memory 35 (step S16).

Then the operator sets the object sample S in the measuring apparatus (step S17). At this time, the position of measurement can be correctly specified similarly to the first embodiment. Thereafter the operator supplies a measurement command to the control unit, whereby steps S18 to S22 are carried out in response to a command from the control unit. That is, the ultraviolet light L_{UV} is applied to the surface of the object sample S (step S18), and energy E_S of the light reflected by the said surface is measured by a spectroscopic unit 32 (step S19).

A signal relating to the energy E_S of the reflected light is supplied from to the spectroscopic unit 32 the arithmetic unit 34, while the values of the energy E_P and the absolute reflectance R_P are read from the memory 35, so that absolute reflectance R_S of the object sample S is operated on the basis of the following expression (step S20):

$$R_S = (R_P/E_P) \cdot E_S \quad (3)$$

The reason why the absolute reflectance R_S is obtained from the expression (3) is as follows: It is generally known that the following relation holds between the energy E_P of the light reflected by the reflectance-known sample P and the absolute reflectance R_P of the reflectance-known sample:

$$E_P = K \cdot R_P \quad (4)$$

Symbol K represents a value specific to the apparatus measuring the said energy E_P . In the aforementioned film thickness measuring method, energy values of the reflected light of the reflectance-known sample P and the object sample S are measured by the same apparatus, and hence the following relation holds:

$$E_S = K \cdot R_S \quad (5)$$

The expression (3) is derived from the expressions (4) and (5).

On the basis of the absolute reflectance R_S obtained at the step S20 and the correlation data stored in the memory 35, the thickness of the transparent thin film formed on the object sample S is obtained (step S21), and the thickness value is displayed on a display unit (not shown) (step S22).

An effect similar to that of the first embodiment can be obtained in the second embodiment, since the energy of reflected light is measured through the light of the ultraviolet region similarly to the first embodiment.

Although an exemplary method of obtaining film thickness through the relation holding between absolute reflectance and film thickness in relation to the second embodiment, the method of deriving the film thickness is not restricted to this. For example, the ratio of absolute reflectance R_S obtained from reference etc. to absolute reflectance R_P of a reflectance-known sample P may be operated every film thickness d_x to store correlation between the film thickness d_x and the ratio (R_S/R_P) in the memory 35 and to thereafter perform division E_S/E_P with respect to energy E_S of light reflected by an object sample S in the film thickness calcu-

lating unit 36 for retrieving the memory 35 with an address of the value E_S/E_P to thereby regard film thickness stored with an address of R_S/R_P being coincident with or approximate to E_S/E_P as that of the transparent thin film.

In the aforementioned second embodiment, at a constant wavelength in the ultraviolet region, the correlation data of absolute reflectance and film thickness and energy of reflected light from the reflectance-known sample and the object sample S must be obtained. Although the wavelength may be arbitrarily set so far as the same is within the ultraviolet region, the same is preferably selected within a range of 180 to 240 nm.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

What is claimed is:

1. An apparatus for measuring an object thickness of a transparent thin film provided on a substrate of an object sample to be measured, said apparatus comprising:

a light source for emitting ultraviolet light; illumination means for illuminating said transparent thin film of said object sample by using said ultraviolet light, said illumination means comprising an optical system;

measuring means for measuring an energy of ultraviolet light reflected by said transparent thin film of said object sample;

memory means for storing correlation data showing a correlation between energy of ultraviolet light reflected by a reference transparent thin film and thickness thereof;

calculating means for calculating an object thickness of said transparent thin film on the basis of said measured energy and said correlation data; and

monitor means for monitoring a film surface of said transparent thin film, thereby focusing said optical system and confirming a measuring position thereof with respect to the transparent thin film, wherein said monitor means comprises a visible light source for emitting visible light, shutter mirror

means for selectively transmitting either said visible light or said ultraviolet light to said illumination means for illumination of said transparent thin film thereby, and image forming means for forming an image of said film surface on the basis of said visible light reflected by said transparent thin film and for displaying said image,

said monitoring means further comprises a reflecting mirror for transmitting said visible light reflected by said transparent thin film to said image forming means, and

said reflecting mirror has a pinhole for transmitting said ultraviolet light reflected by said transparent thin film to said measuring means.

2. An apparatus in accordance with claim 1, wherein: said light source emits multi-wavelength light of ultraviolet region, and

said measuring means comprises spectroscopic means for separating said ultraviolet light reflected by said transparent thin film into spectral components, and an optical detector means for detecting said spectral components.

3. An apparatus in accordance with claim 2, wherein: said light source comprises a deuterium lamp.